POLLEN ANALYSIS AND CHRONOLOGY OF A CENTRAL

TEXAS PEAT BOG

APPROVED:

Donald A. Larson

Harold Bold

To my wife JoAnn
for her help and
encouragement.

POLLEN ANALYSIS AND CHRONOLOGY OF A CENTRAL TEXAS PEAT BOG

by

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THESIS

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T.S.P.

April 3, 1968

ABSTRACT

Results from two cores (5.4 and 5.0 m) taken from the Hershop Bog, a Central Texas peat deposit analyzed for fossil pollen and radiocarbon data, indicate that a sharp decline in the arboreal components of the vegetation occurred at the end of the late-glacial pluvial period. Fossil pollen records of other bog sites and a tri-county (50 mile) modern pollen transect are compared with Hershop Bog pollen profiles established from dual correlatable cores. The pollen record suggest the occurrence of arid conditions between 10,000 and 7,000 years B.P. followed by a 4,000 year span of mesic conditions. This apparent mesic period was interrupted about 3,000 years ago by a brief slight-arid period and a return to mesic conditions occurring about 1,000 years B.P.

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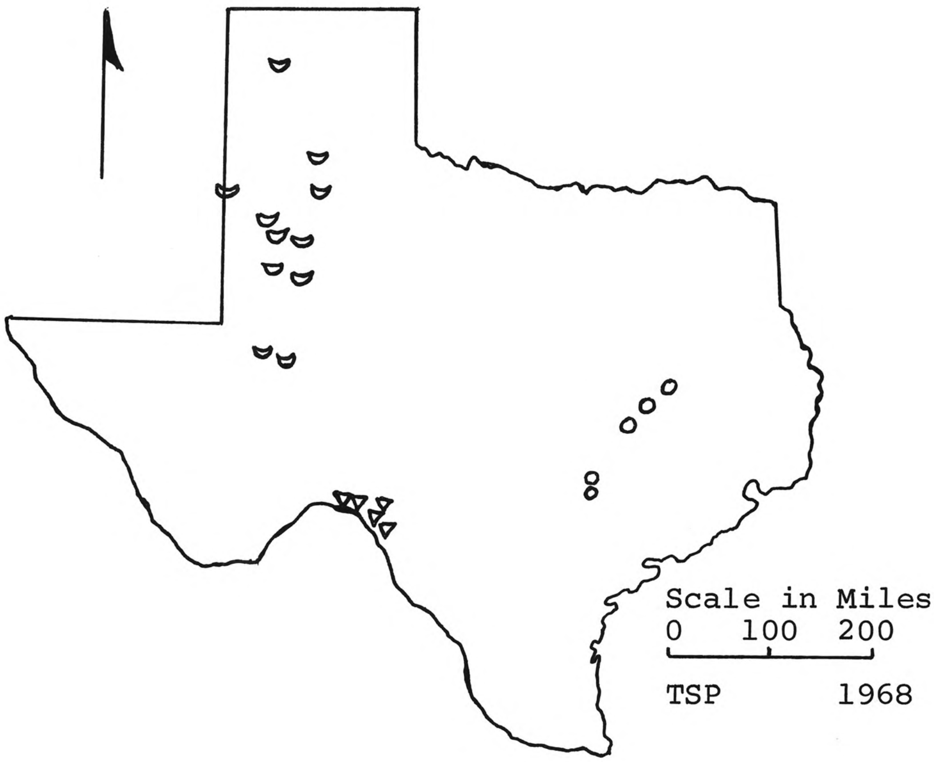
INTRODUCTION

The Pleistocene and post-Pleistocene vegetational history of Texas is as yet incompletely understood. Only a quarter of a century ago peat bog studies began yielding the initial knowledge of late Quaternary vegetation in the Central Texas area. These analytical studies of fossil pollen used to reconstruct past environments in Texas were first conducted by Potzger and Tharp (1943, 1947, and 1954) from three peat bog deposits. Soon to follow was a single probe into a forth peat deposit (Graham and Heimsch, 1960). This probe yielded not only a pollen profile but a radiocarbon date.

In the western half of the state, playa lakes on the Llano Estacado have provided pollen analytic information which reflects vegetational and climatic changes from the Wisconsin glacial period to the recent (Hafsten, 1961; Oldfield and Schoenwetter, 1964). A Blancan-age lake deposit has provided an early Pleistocene pollen record in the Texas Panhandle (Harbour, in press), while archeological sites along the Rio Grande in the Amistad Reservoir area have recently yielded post-glacial records (Johnson, 1963; Bryant, 1966a, 1966b; McAndrews and Larson, 1966; Hevly, 1966). These sites are still under examination. Locations of the pollen analytical sites mentioned above are indicated in Figure 1.

Fig. 1. Texas Pollen Sites.



O Peat Bog Deposits

∇ Archeological Sites

Playa Lakes

The present study will (1) present a peat-bog pollen stratigraphy and depositional chronology as substantiated by dual cores and extensive radiocarbon analysis; (2) evaluate and compare the interpretations of the late Quaternary climatic and vegetational sequences in Texas presented in the previous studies of peat-bog deposits; and (3) seek correlations among the post-glacial pollen records as reflected in the playa-lake and archeological sites with the Central Texas bog sites.

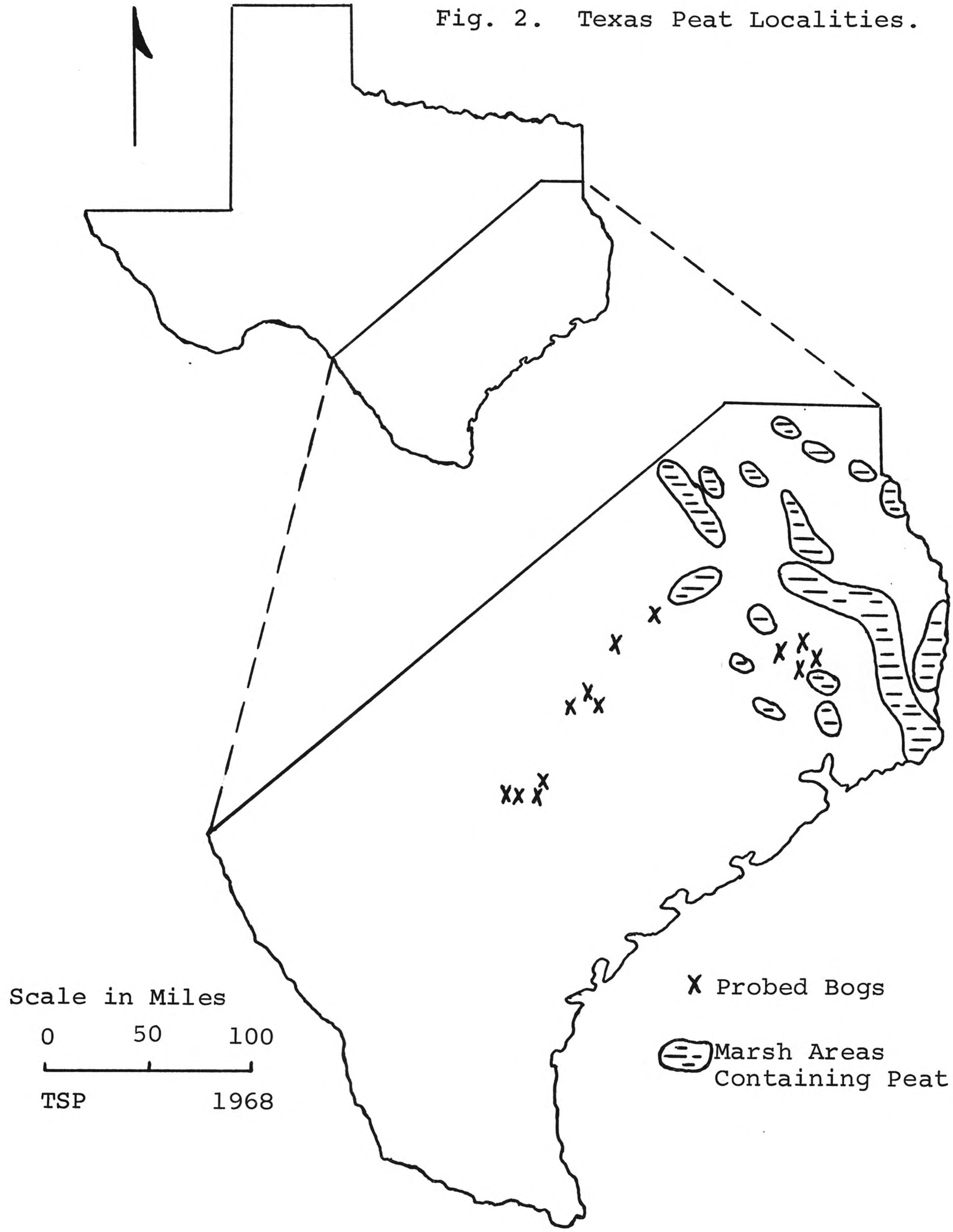
Peat bogs, along with numerous cave, lake, stream-terrace deposits, and the Gulf Coastal Beaumont and Lissie-age sands and gravels represent the Pleistocene and post-Pleistocene series in Texas. Peat deposits consist of accumulated plant fragments in various stages of decay and contain vast sums of pollen preserved under the reduced and acid environment. By careful extraction and identification of the pollen at various levels within a bog, a reconstruction of the past anemophilous vegetational history of an area can be inferred to a reliable degree, and this yields indications of past climatic conditions.

Unfortunately, the humus content and water-absorbing qualities of peat make it a useful item in the horticultural business. With the coming of World War II, the supply of commercial peat from northern Europe was cut off. Not only had the production of peat in the United States been small, as compared to the European sources, but the freight rates by rail from the peat-bog areas of Minnesota, Wisconsin, and New York were high enough to demand the development of peat deposits in Texas to supply the local market (Plummer, 1941), thus destroying a number of important sites.

A unit of the WPA State-Wide Mineralogical Survey of Texas, sponsored by The University of Texas Bureau of Economic Geology, set out in 1940 to discover and to evaluate economic deposits of peat in Central and East Texas. Several bogs were located and numerous marshes containing peat deposits were also examined (Fig. 2). Deposits along Yegua Creek in Lee County yielded commercial quantities of peat in 1940 (Plummer, 1941). Several peat deposits in Polk and San Jacinto Counties were examined and probed (Shafer, 1941). Many marshes containing deposits of peat are associated with all of the major river systems in East Texas (Fisher, 1959).

One of the deposits in Gonzales County, the Hershop Bog (named after the late George Hershop, owner of the estate on which the bog was found in 1940), is the site for the present study. In a recent Bureau of Economic Geology Report of Investigations (Maxwell, 1962) this bog carried the name "Fred Alex Bog" named after the present landowner, Fred Alex, nephew of the late George Hershop.

Fig. 2. Texas Peat Localities.



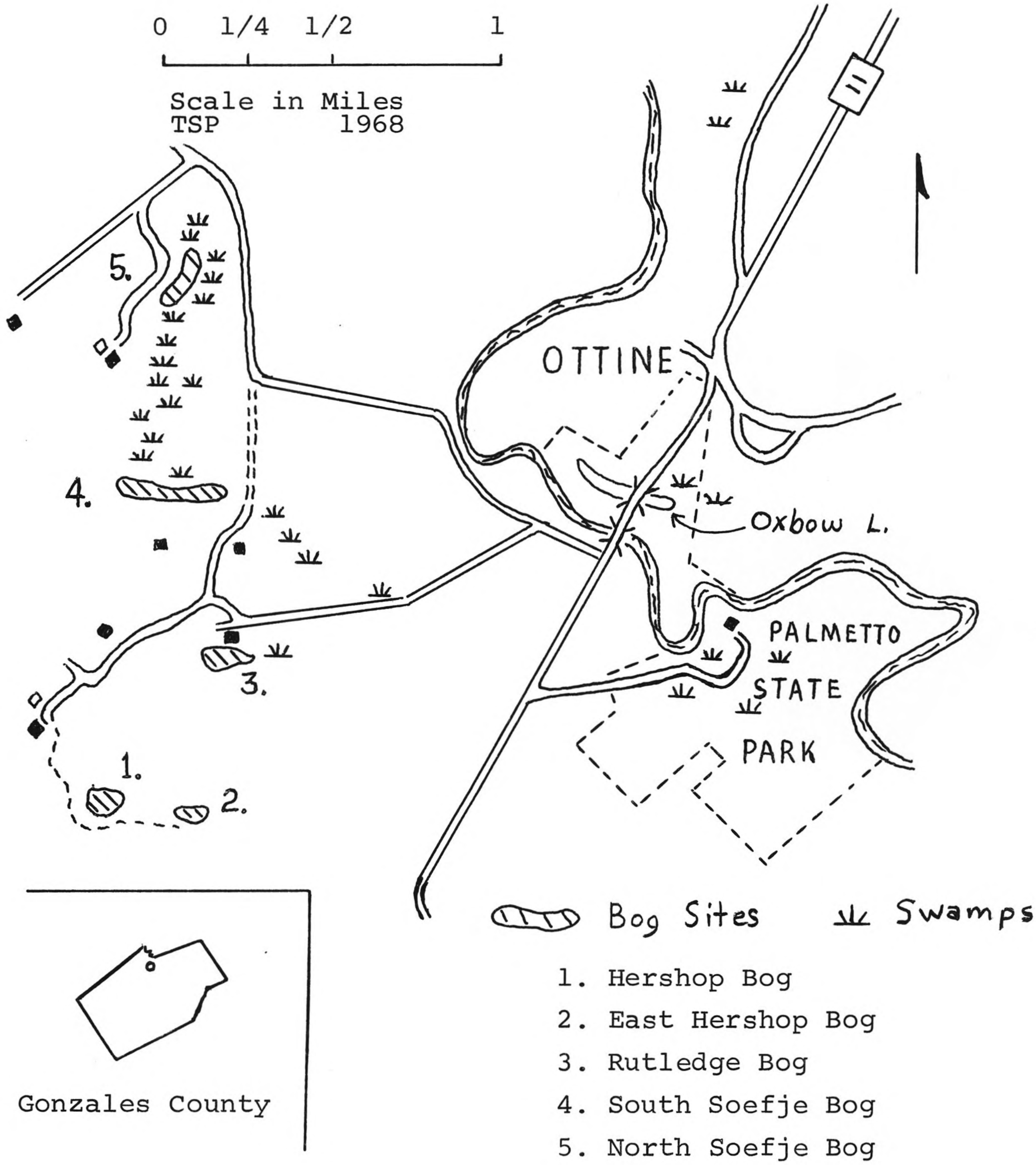
LOCATION, TOPOGRAPHY, GEOLOGIC SETTING, AND VEGETATION

The Hershop Bog is located on the Fred Alex farm two miles southwest of the village of Ottine, Gonzales County, Texas, as illustrated on the area map in Figure 3. Map distance is ca. 60 miles E.N.E. of San Antonio, 50 miles S.S.E. of Austin, and 10 miles N.W. of Gonzales. The coordinates of the bog are lat 29°35'N.; long 97°36'30"W. Its elevation is 340 feet above sea level.

The present elevation of the San Marcos River two miles northeast of the bog is 290 feet. The flood plain of the river, used for cultivation and grazing, has a minimum elevation of 320 feet and lies within a mile distance of the Hershop Bog site, while upland areas, one half mile or so to the west of the site, are over 400 feet in elevation.

The meander belt of the San Marcos River, trending southeast in the area, intersects the Carrizo (Eocene) formation, a ferruginous sandstone which strikes NE-SW through Gonzales County. The Carrizo is a good aquifer and supplies the area with artesian and well water. The formation makes contact with flood-plain deposits at an elevation of ca. 320 feet and forms numerous seeps in the area. Near-by bogs, the Rutledge, and both the North and South Soefje Bogs, owe their origin to seepage from the Carrizo sands.

Fig. 3. Area Map of Ottine, Gonzales County, Texas.



The Palmetto State Park, about two miles northeast of the Hershop Bog site and dissected by the San Marcos River, lies entirely on the flood plain and contains many swamps and boggy areas.

Most of the bogs in Gonzales County exist under conditions which duplicate the areas of other bog sites in Texas (Fig. 2). These include rainfall of 35 or more inches per year, gently rolling topography, and hillside or meander-belt locations. As a matter of convenience, peat deposits in Texas are placed by this writer into two main classes: (a) flood-plain-bounded and (b) upland-area. Most of the Texas bogs fall into the first class. They are formed as a result of the slow filling of oxbow lakes or abandoned meanders. Also included in the first class would be the bogs formed by seepage at the base of hillsides in contact with, and normally formed on, the flood plain. Other peat deposits result from the filling of upland depressions and sinks, usually are fed from perched water tables, and fall into the second class.

Water slowly percolating through the permeable Carrizo sands ultimately reaches impermeable layers. It then moves laterally and, in regions of rolling topography and stream dissection, can reappear at the surface as springs or seeps. The depositional environment (topography, water availability and climate) in which plant fragments accumulate with incomplete decay determines the depth to which the peat can accumulate. This writer, using steel rod probes, has found peat accumulations in Central Texas ranging from 0.25 meters to just over 6 meters in depth.

The Hershop Bog is interpretated by this writer to be an upland-area bog. It is situated well beyond the upper limits of the flood plain (about 20 feet) and its origin is the result of an upland area depression dissecting a perched water table and being filled by plant fragments. Large blocks and boulders of Carrizo, the aquifer supplying the water, can be observed outcropping along the sandy hillsides above the bog.

The Hershop Bog, as can be seen in Figure 3, is situated about a mile south of the South Soefje Bog and is topographically above it by about 20 feet. This bog is unsilted and appears to have been free of erosional breaks during active deposition. However, the present peat area exposed is much smaller than the original active bog area because sand has recently washed down from the hillside covering the edges of the deposit. With a steel probe, a total bog area of almost 500 feet in diameter has been examined by this writer. Early study of the bog (Chelf, 1941) included analyses of moisture, ash, and pH. A reported pH range from 3.6 to 4.7 was within the range obtained by this writer. One sample from cores taken for this study was observed to have a pH of 2.8. Chelf (1941) also reported that the Hershop Bog ranged in thickness to about 20 feet, but on a profile of the bog, the vertical scale was such that the thickness would be 50 feet. This error was picked-up and reported again some years later (Maxwell, 1962). Extensive probing demonstrated that the Hershop Bog has a maximum depth of 5.4 meters, or about 17.5 feet.

In order to make significant evaluations of a fossil pollen profile the distribution of local extant species should be considered. Studies of Texas plants, fragmentary and basically unsystematic, date back to field observations in the early 1800's. Plant lists of Palmetto State Park, one and a half miles northeast of the Hershop site, were compiled in the early part of this century by Bogusch (1928) and Parks (1935). The vegetation of the general area has been designated by Tharp (1939) and Blair (1950) as an oak-hickory association. Gould (1962) placed the northwest quarter of Gonzales County into a post-oak savannah but mentions that others prefer to class the area as part of the true prairie association of the grassland formation. This latter view is based on the fact that the understory vegetation is typically tall native grasses.

Along the hillsides adjacent to the Hershop Bog site, the dominant trees are _Quercus stellata_ Wang. (post oak), _Q. marilandica_ Muench. (black-jack oak), _Q. viginiana_ Mill. (live oak), _Q. macrocarpa_ Michz. (bur oak), _Ulmus americana_ L. (American elm), and _Prosopis glandulosa_ Torr. (mesquite). _Juniperus virginiana_ L. (cedar) can be seen in the vicinity but is a very minor component. Next to the bog and toward the flood plain are Carya illinoensis (Wang.) K. Koch. (pecan), Salix nigra Marsh. (black willow), Populus deltoides Bartr. ex Marsh. (cottonwood), Vaccinium arboreum Marsh. (huckleberry), and Celtis pallida Torr. (hackberry). Closer to the flood plain Fraxinus americana L. (ash), Myrica cerifera (L.) Small. (wax myrtle), Ilex decidua Walt. and I. vomitoria Ait. (yaupon) can be found.

Plant species not now growing in the vicinity of the Hershop Bog, as well as their present distribution, should be noted in relation to the fossil-pollen findings. Pines (i.e., P. taeda), in recent years, have been planted along Highway 90 ca. 10 miles north of the study area. Isolated native stands of pines, common in the eastern part of the state, occur 30 miles or so farther north in Caldwell and Bastrop Counties. The species represented in the Bastrop State Park area is P. taeda L. (loblolly). It has been reported by Critchfield and Little (1966) that a minute isolated stand of P. palustris Mill. (longleaf pine) exists in far eastern Gonzales County some 25 miles from the bog site. Pinus echinata Mill (short leaf pine) grows in East Texas in association with the loblolly and longleaf pine about 125 miles northeast of the study area. Liquidambar styraciflua L. (sweet gum) grows in East Texas some 150 miles away. Alnus rugosa (DuRoi) Spreng. (alder) is also found in East Texas along the Trinity River, and Betula nigra L. (river birch) is native to East Texas.

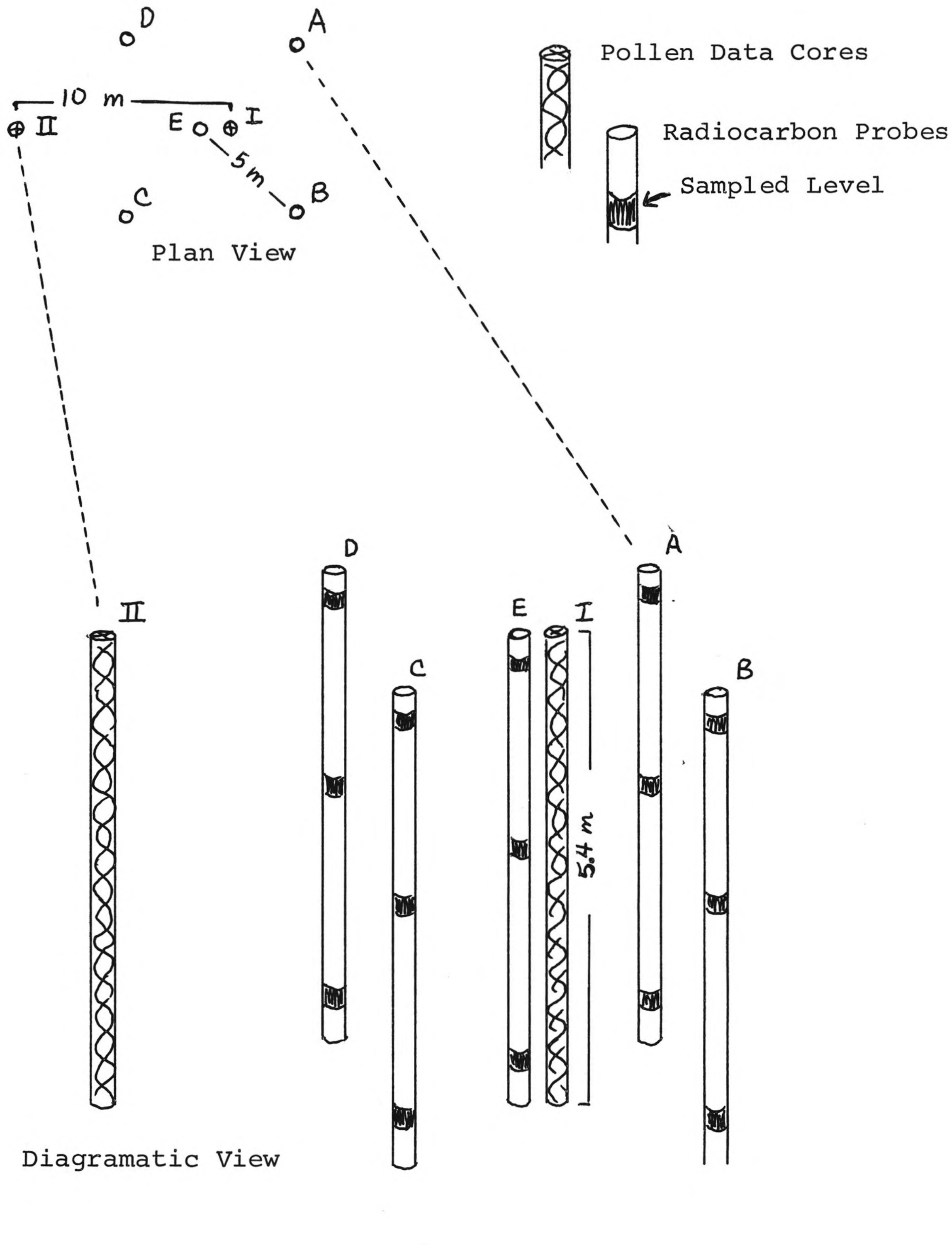
According to the landowner, a long-time resident, the Hershop Bog was active with cattails and other bog plants covering the surface up until the late 1940's. Where water drains from the bog, ferns, mosses, and cattails (Typha sp.) are still present. At present the bog is "dead" and, with no protective covering of plants, is undergoing surface erosion and silting. The bog is slightly domed in the middle and "quakes" when jumped upon.

MATERIALS AND METHODS

Peat Samples

After probing the Hershop Bog to determine its basal conformation and to identify its greatest depth, two complete peat cores were taken for pollen analytic purposes. These cores were obtained with a Hiller borer. Actually, Core I was collected on August 8, 1967 while Core II, for stratigraphic correlation, was obtained on February 1, 1968. Peat samples from each retrieved core were removed in 10-cm segments and placed in labeled glass jars and sealed. A record was made of color, compactness, odor, degree of decomposition, and sand content of each sample. Permineralization and total replacement of plant stems by pyrite (FeS_2) were observed in the lowest bog samples. The deposit was cored to a depth of 5.5 meters before resistance was met. When the bottom cylinder of peat was brought up and opened, the lowermost 10-centimeters was composed of clean, fine-grain, well-sorted Carrizo sand. Fifty-four samples of 10-cm increments were taken for a total recovered core of 5.4 m and designated as Core I. The second core was taken 10 m west of Core I and had a total depth of 5.0 m (See coring diagram Figure 4).

Fig. 4. Hershop Bog Coring Diagram.



Radiocarbon Samples

Peat from the Hershop Bog to be analyzed for Carbon-14 was obtained and submitted to The University of Texas Radiocarbon Dating Laboratory in November, 1967. The samples were obtained by means of a Hiller borer in 20-cm increments. Three arbitrary levels were used: 0.3-0.5 m (upper); 2.3-2.5 m (middle); 4.9-5.1 m (lower). Five probe areas designated as A, B, C, D, and E were selected. The first four mark the corners of a square with diagonals 10 m long and probe area "E" in the center as illustrated in the plan view in Figure 4. The five probe areas were centered over the deepest part of the bog with probe "E" located 50 cm from Core I used in pollen analysis.

A total of 45 penetrations were made in the process of acquiring peat samples for radiocarbon processing. This means that at each probe position three samples were obtained from each of the depth levels. The three samples from each depth level at a probe point were placed together in a plastic bag and sealed. This composite sample was then used in dating. Washing of the Hiller borer with distilled water after each sample protected against contamination, and peat was removed by a carefully cleaned spatula also insuring against contamination.

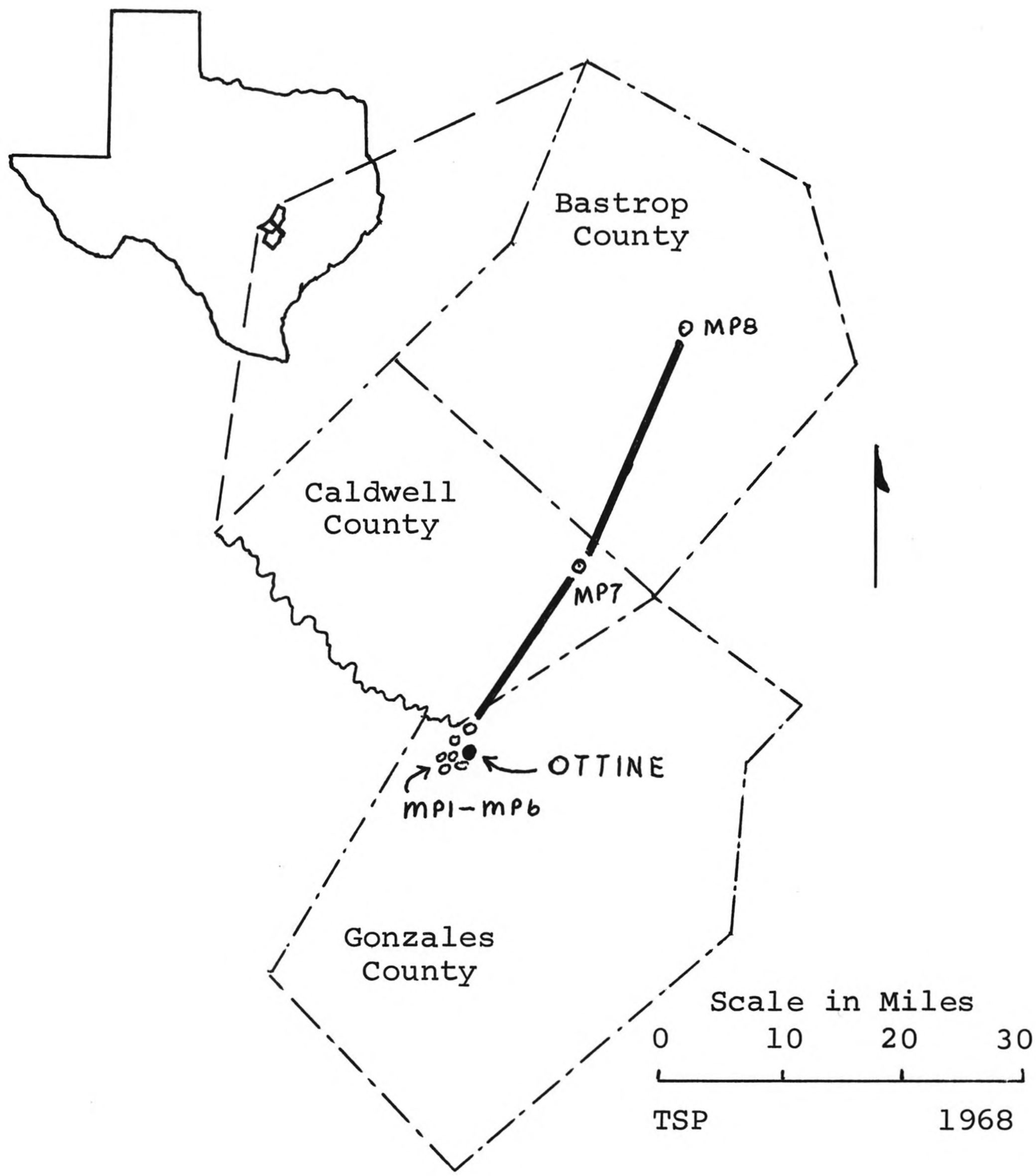
Modern Pollen Surface Transect

Eight surface-soil samples, taken from a 50-mile tri-county transect, were collected and analyzed during the course of this study. Six samples were taken along a four-mile transect in a general NE-SW direction in the vicinity of the Hershop Bog. Of the other two, one was collected ca. 100 m from a small trend of native pines in northern Caldwell County, and one was taken within Bastrop State Park in Bastrop County. The collecting site in Caldwell County was an oak-mesquite woodland, whereas, the Bastrop site was within an oak-pine woodland. The transect within Gonzales County spans the entire flood plain of the San Marcos River and adjacent upland areas. The sampling sites are designated as MP1 through MP8 as illustrated on the area map as Figure 5. The collections were made during February, 1968, by the writer, and consisted of several handfulls of surface dirt sampled over an area of ca. 100 m^2. The samples were placed in labeled plastic bags and sealed. To avoid any gross overrepresentation of a species which might occur in any one spot, the samples in the bags were shaken and thoroughly mixed. The sampling sites were spaced to provide information about the modern pollen rain over a diverse topographic and vegetational range.

Extraction and Preparation

The University of Texas Brackenridge Field Laboratory houses the facilities used in the processing of the Hershop Bog samples. The fully air-conditioned, positive-pressure Palynology Research room has equipment for all types of pollen extraction techniques.

Fig. 5. Map of Modern Pollen Transect.



A small amount (2-3 cc portion) of peat from each of the 10-cm increments was processed by a modification of the acetolysis treatment described by Faegri and Iverson (1964). A detailed description of the seven basic steps used in extracting fossil pollen from the peat samples is given in the Appendix.

Additional preparation of the samples consisted of mounting the 2.0% Safranin-stained palynomorphic material. A drop of the concentrate suspended in silicon oil (2000 cs) was placed on a labeled microscope slide, covered with a coverslip, and sealed with fingernail polish (Anderson, 1960). All unused portions of Core I and II, duplicate-processed concentrate, and prepared slides are catalogued and stored as part of the fossil pollen reference collection. These samples are accessible to any worker desiring refinement or verification with any future work.

Pollen Reference Collection

Reference material used in the identification of the Hershop Bog pollen types consisted of the Amistad Pollen Collection (Bryant, 1966c) and a collection of pollen extracted by this writer from specimens on herbarium sheets in The University of Texas Herbarium. The pollen types selected for the reference collection are from species known to exist in the Hershop Bog area today and from plants such as *Betula* and *Liquidambar* which do not now grow in the vicinity of the bog but appear in the fossil pollen record.

The Amistad Pollen Reference Collection has a prepared pollen key (McAndrews, 1966) for 250 pollen types. Vaughn Bryant, this writer, and others have tripled the size of the reference collection which now includes plant types from all over Texas and adjacent areas. This reference collection, including the Amistad collection, is currently housed in the Palynology Research room of The University of Texas Brackenridge Field Laboratory. Identification of pollen types in this report are based upon comparative studies with the mentioned reference material.

Pollen Counts

All pollen counts were made with an oil-immersion objective at 970X. The 54 samples in Core I were examined for all pollen and spores (excluding fungal spores) using a standard 200-grain count (Barkley, 1934), this provided a primary count. A secondary count which excluded all trilete grains was obtained from Core I. Grain counts for the 5-M correlation core (Core II) were obtained using a fixed sum of 150 grains and excluded all spores and trilete grains. As each grain was identified, it was scored on a tabulation sheet and recorded on a mechanical hand counter. Whole grains and fragments (such as pine bladders) of known pollen types were included in the standard counts. Although the fungal spores were excluded they were not ignored. Highly distorted, crushed, and deteriorated grains which could not be identified were also excluded from the counts. Pollen counts using fixed sums of 200 were obtained from each of the surface soil samples.

Pollen Diagrams

The primary pollen profile, a standard 200-grain count, included all recognizable pollen types and trilete grains. The secondary pollen profile summarizes the data from a second count totalling 200 grains but excluding trilete types. (Fig. 7). Data for the secondary pollen profile was obtained by using the sum of the non-trilete grain types tabulated from duplicate slides for corresponding levels. For example, from processed peat at a depth of 310 cm (3.1 m), a total of 48 trilete grains (24%) was tabulated in the primary count. From a duplicate slide a second count was made of 48 non-trilete grains and added to the 152 non-trilete grains from the primary count, thus giving a total of 200 grains. Unless otherwise stated the discussion in this report refers to the results of the secondary count.

A pollen profile illustrating the arboreal pollen in relation to non-arboreal pollen was constructed by totalling all of the tree-pollen percentages and plotting them against the remaining elements of the pollen counts (Fig. 8). The non-arboreal component of the diagram includes the unknown pollen types which averaged about two percent. Superimposed on the profile of Core I is an arboreal-non-arboreal profile from Core II. This provides graphic illustration of the relationships between pollen percentages in the two cores.

Observations

Observations for this report were made with an A. O. Spencer phase-contrast binocular microscope with objective lenses of 10X, 43X, and 97X. The oculars were 10X. All pollen counts were obtained under oil at 970X followed by scanning under 100X and 430X for unusual pollen types not observed in the standard sums.

RESULTS

Radiocarbon Dates

Radiocarbon dating of the Hershop Bog has yielded a maximum date of 10,920$\pm$160 years B.P. from peat approximately 0.5 m above the sands at the deepest known point (5.4 m). The complete set of dates as released by Dr. E. Mott Davis, director of the Radiocarbon Dating Laboratory are listed in Table 1.

When examining these dates, the reader should understand that the date represents an average obtained from the analysis of a bag of peat collected over a 20-cm stratigraphic range. For example, the upper level of Radiocarbon Coare "A" an age of 2,340$\pm$80 years B.P. is obtained from a unit of peat ranging between 0.3 m and 0.5 m depth (Fig. 4). In the upper and middle levels of the Radiocarbon Cores, the depth of the 20-cm increments was consistent, but in the lower level, because of variation in bottom depth and sand content of the cores, all increments were not taken from the same level. The exact depths are indicated under the dates listed in Table 1. As shown in the table, an approximate date is also indicated for each of the three levels. The date represents an average and is not intended for any specific depth but applies to the depth range from which the peat was sampled. Henceforth, the

TABLE 1

RADIOCARBON DATES FROM HERSHOP BOG

Level	Core A	B	C	D	E	Average
Upper	2,340±80* (0.3-0.5m)	1,960±100	2,120±90	1,520±80	2,170±90	2,022
Middle	6,150±130 (2.3-2.5m)	5,980±100	5,850±120	6,000±130	6,050±100	6,006
Lower	10,920±160 (4.8-5.0m)	10,450±160 (4.4-4.6m)	10,490±160 (4.8-5.0m)	10,560±160 4.9-5.1m)	10,450±160 (4.9-5.1m)	10,574

*All dates are before present (B. P.).

average dates and the depth ranges are included in the pollen diagram for general purposes but definitive dates must be read from Table 1.

Figure 6 illustrates the relationship of the Hershop Bog radiocarbon dates to the corresponding depths. Straight lines connect the points of average depth and average age for each sample taken. Dates used in this report for depths not sampled are extrapolated from the three-point curve and are intended to be only approximations.

Pollen Analysis

The Hershop Bog cores and the modern pollen transect yielded 33 pollen types representing 25 families (Table 2). Four of these types (*Acer*, *Alnus*, *Betula*, and *Liquidambar*) were found only in the fossil record, whereas, *Acacia* was found only in the modern pollen rain. *Prosopis*, a dominant tree in the immediate area of the bog, was encountered only in the upper 10-cm increment. *Prosopis* composed three percent of the modern pollen rain collected near the bog (MP1). The results of fossil pollen processed from Core I are represented by Fig. 7 for the primary and secondary count.

The primary fossil pollen profile represents percentages of pollen and trilete moss and fern spores based on the standard 200-grain count. A general survey of fungal spores was made not to make some evaluation as to their significance but to see how they rank in number compared to

Fig. 6. Hershop Bog Radiocarbon Dates with Corresponding Depths.

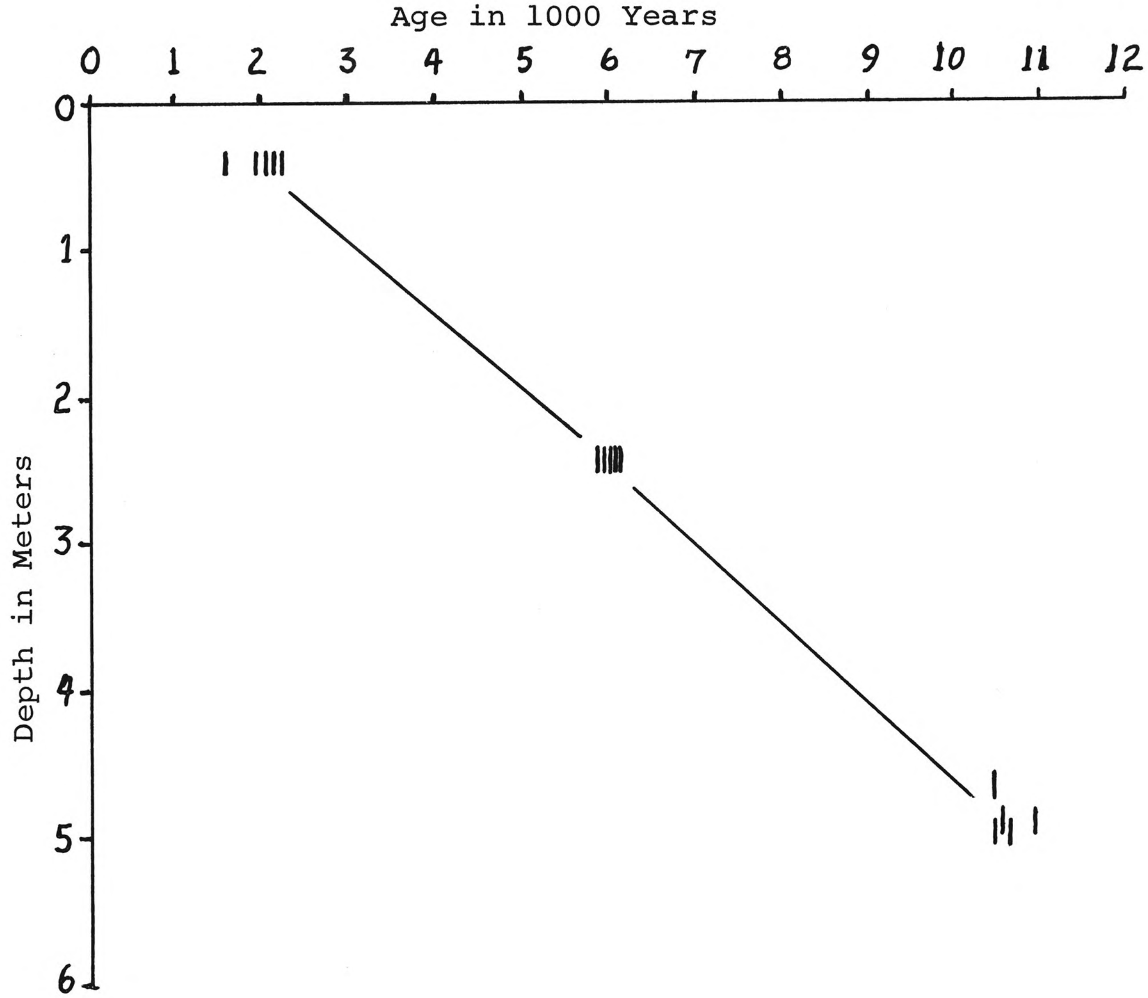


TABLE 2

POLLEN TYPES OF THE HERSHOP BOG AND SURFACE TRANSECT

ACERACEAE

Acer

AQUIFOLIACEAE

Ilex

CACTACEAE

CHENOPODIACEAE-AMARANTHACEAE

COMPOSITAE

High-spine types

Ambrosiaceae

Liguliflorae

Artemisia

CORYLACEAE (BETULACEAE)

Alnus

Betula

CYPERACEAE

ERICACEAE

FAGACEAE

Quercus

GRAMINEAE

HAMAMELIDACEAE

Liquidambar

JUGLANDACEAE

Carya

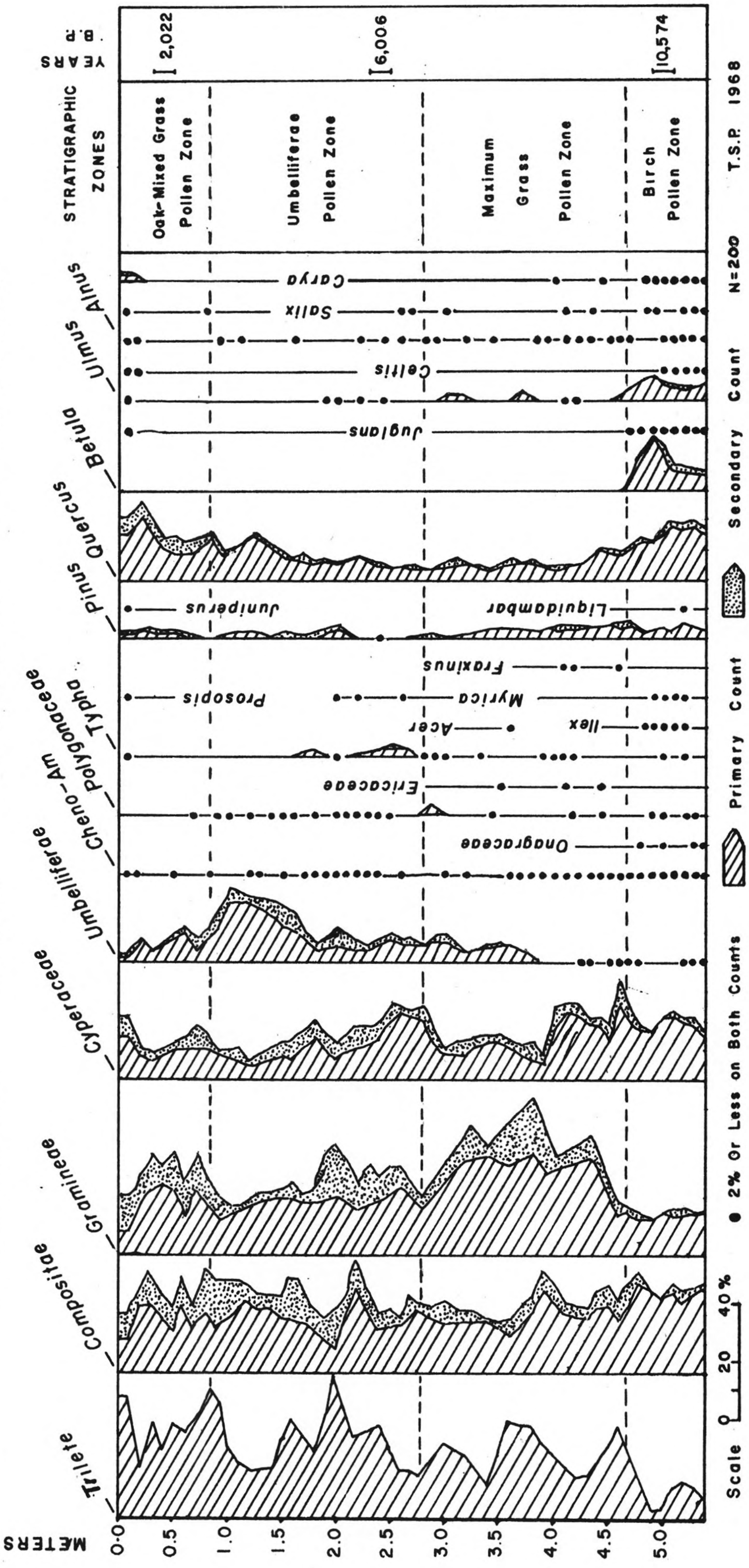
Juglans

TABLE 2 (Continued)

LIGUMINOSAE
Prosopis
Acacia
LYCOPODIACEAE
Lycopodium
MYRICACEAE
Myrica
ONAGRACEAE
PALMACEAE
Sabal
PINACEAE
Juniperus
Pinus
POLYGONACEAE
SALICACEAE
Salix
SELAGINELLACEAE
Selaginella
TYPHACEAE
Typha angustifolia
T. latifolia
ULMACEAE
Celtis
Ulmus
UMBELLIFERAE

Figure 7

HERSHOP BOG POLLEN PROFILE

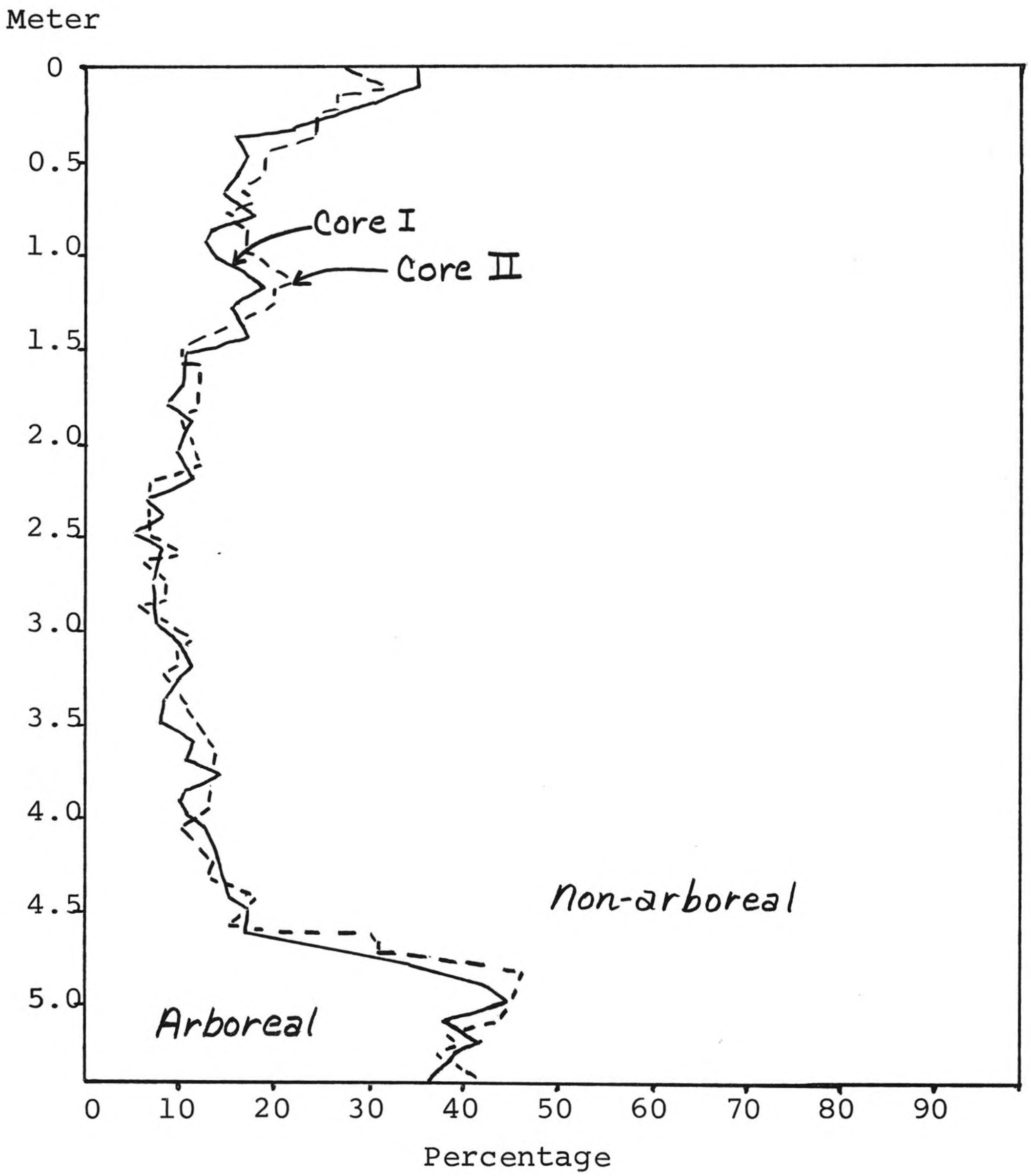


the pollen. In the lower meter of the Hershop Core I samples, counts were made of 200 grains which included fungal spores. The percentages of fungal spores ranged from 11% to 30% with an average greater than 20%. Pollen from almost any level of the bog, particularly the grass, often appeared to be in various stages of deterioration perhaps due to some sort of fungal activity. This writer observed several surface-soil samples collected for the transect in which 90% of the pollen showed signs of fungal attact; pollen was absent altogether in certain samples. Graham (1962) discusses the possibility of the use of fungal spores in palynology but this problem is outside the scope of this paper. The counts obtained for the profiles exclude all fungal spores.

If the gross trends in the pollen assemblages represented on the pollen diagrams are examined, it can be seen that the non-arboreal pollen comprises the bulk of the profile except for the base and upper segment of the bog. Dividing the pollen types into two main groups (the arboreal and non-arboreal) and then plotting the percentages, the resulting profile nicely summarizes the trends (Fig. 8). The relationship between arboreal and non-arboreal types can be compared for any depth. For example, it can be shown that in the lower 0.5 m (5.4-4.9 m) of the Hershop sediments, arboreal pollen contributed 40% or better of the total preserved pollen.

Birch Pollen Zone. The lower peak in the tree pollen is reached at a depth of 5.0 m with a maximum of 44% (as

Fig. 8. Percentage of Arboreal Pollen in Relation to Non-Arboreal Pollen of Core I and Core II from Hershop Bog.



illustrated in Fig. 7). The major tree types which make up this bulk are Quercus, Betula, Ulmus, and Pinus, the latter adding only 3%, whereas the first three add 17%, 14%, and 4%, respectively. This stratigraphic zone is designated as the Birch Pollen Zone in accordance to Cushing's (1964) Code of Stratigraphic Nomenclature. The age of the lower tree peak is ca. 11,000 years B. P. as indicated by the results of the radiocarbon analysis. An approximate date of 12,000 years is assumed for the beginning of the bog deposition. The radiocarbon analysis provides a minimum age for the end of the Birch Pollen Zone of ca. 10,000 years B. P. This lower zone has Salix and possibly Liquidambar present. Salix is not restricted to this zone, whereas, a type identified as Liquidambar was observed only in the 5.2-m sample. Juglans ranged throughout this lower zone in percentages of 2% or less. Betula was recovered from every level between the bottom and the 4.7-m level. Both Betula and Juglans dropped from the fossil record above this level, except that the latter was again recovered from the upper 10-cm segment at about 2%. Carya and Celtis also have this basic pattern, present in the lower levels, absent for the most part in the middle portion of the strata, and reoccurring in the upper 10-cm segment. The Ulmus peak is in the lower portion also but observed frequently at other levels in the section.

The non-arboreal components of the Birch Pollen Zone can be characterized by a low percentage of Gramineae, a near absence of Umbelliferae, and, as seen in the primary pollen profile, the trilete (moss and fern) types are at their minimum. *Ilex* is only represented in this lower zone in the fossil record along with Onagraceae. *Ilex* was identified in the modern pollen rain from samples taken along the flood plain boundary (MP5). Cyperaceae reflects a relatively high percentage (averages somewhat above 20%) in this lower pollen zone.

Maximum Grass Pollen Zone. With the sharp decline in arboreal pollen types, there is a corresponding increase in non-arboreal types. The grass curve begins increasing at 4.9 m passing the 40% mark at 4.3 m. The grass pollen peaks at a maximum 53% at the 3.8 m level. This zone of sharp rise in grass pollen, above levels in which *Betula* pollen is found and up to the 2.8 m level, is designated as the Maximum Grass Pollen Zone. During the time represented by this portion of the bog, arboreal pollen was at its lowest percentage. Recovered pine pollen ranged at only 1 or 2%, *Quercus* from 5 to 10% and *Alnus*, *Salix*, and *Fraxinus* each contributed 1% or less to the pollen counts. Cyperaceae pollen was also reduced in percentage, whereas, Umbelliferae pollen was beginning its rise. At the end of the Maximum Grass Pollen Zone, the grass pollen fell to 20%. The approximate age of 7,000 years B. P. is assumed for this time. A sudden rise in *Typha*, *Polygonaceae*, and *Cyperaceae* with an ever-increasing rise in Umbelliferae marks the end of this period.

Umbelliferae Pollen Zone. This zone is characterized by the constant increasing rise in umbelliferous pollen types. Another feature is a gentle rise in oak (4% to about 18%). The Cyperaceae and, generally, the grass pollen decline from bottom to top in this zone. The Compositae range about 30% compared to an average of 20-25% in the zone below. _Typha_ is present in this zone up to 4%. The upper limit of this zone corresponds to the sudden decline in the Umbelliferae recovery (from 25% to less than 10%) and the increase in oak and grass pollen.

Oak-Mixed Grass Pollen Zone. At the 0.8 m level, there is a pronounced peak in the oak curve. The same level is also marked by an increase in Gramineae and Cyperaceae. For the next 30 cm the latter, as well as Umbelliferae, decreases and the oak curve becomes stabilized. The upper portion of this zone is characterized by a noticeable decline in Compositae and Gramineae with an ever increasing Cyperaceae and oak curve. _Juglans_, _Alnus_, _Carya_, and _Celtis_ contribute to this zone especially in the upper 10-cm portion. _Prosopis_ also is observed in this segment. Although in small percentage (2%), _Ulmus_ contributed to the arboreal pollen for this upper pollen zone. An assumed age of just less than 1,000 years B. P. is placed on the reoccurrence of the riparian elements observed in the upper core segment (an unknown amount of peat has been eroded from the present bog surface).

Modern Pollen Rain

The transect of surface-soil samples across three counties provides information about changes in local modern pollen rains with respect to topography and plant distribution. The transect covers a map distance of almost 50 miles and trends roughly NE-SW as illustrated in Figure 5. Eight samples were collected and processed. One in Bastrop State Park (MP8) Bastrop County, one in mid-eastern Caldwell County (MP7) and the remaining six in Gonzales County. The elevation ranged from ca. 460 feet in Bastrop County ot ca. 218 feet on the flood plain of the San Marcos River in Gonzales County.

A diagram showing the modern-pollen rain obtained from the surface samples is represented as Figure 9. It is possible to separate several geographic and topographic zones from each other by using the modern-pollen rain. High pine recovery is in the pine forest in Bastrop County, but long-distance transport results in pine pollen being found also in surface samples from Caldwell and Gonzales Counties. The percentage of pine in the surface soils within the five-mile radius of the bog site matches the percentage recovered in the upper levels of the peat cores (ca. 2%). Samples taken from the oak-mesquite upland area (MP6) north of Ottine shows *Quercus* and *Prosopis* as dominant tree-pollen types with *Acacia* and *Ulmus* as associated types. In the same location, Compositae and Gramineae dominate the herb-pollen segment of the pollen sum.

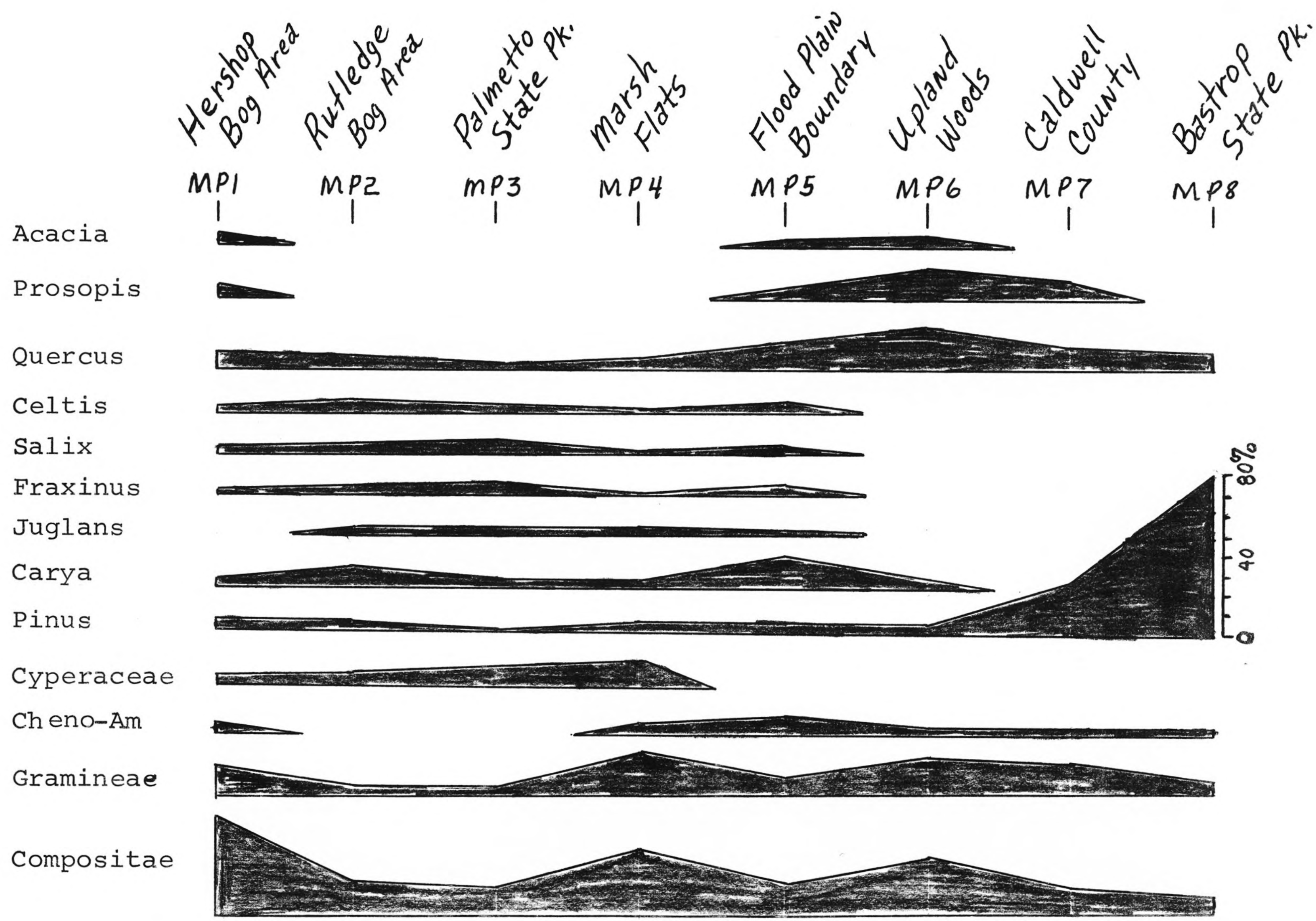


Fig. 9. Modern Pollen Rain

From the upland collecting site to the flood plain boundary (MP5), the elevation drops from ca. 425 feet to ca. 340 feet. There is a marked change in the vegetation from the two sites. Seepage zones are common along the flood plain boundary and the vegetation is dense. The modern-pollen rain reflects this change in the percentage of upland-area types and exchanges with several others. *Ilex* and Malvaceae show up as well as certain riparian types such as *Celtis*, *Salix*, and *Fraxinus*. *Ulmus* and *Carya* take over as dominant tree types, along with *Quercus*, on the rich soil flood plain. *Prosopis* pollen falls off quickly from the upland area to the flood plain. The pollen rain offers a challenge for the expert in oak pollen. The upland area oaks are *Q. stellata* and *Q. marilandica* while the flood plain border oak is *Q. virginiana*. Analyzing the surface pollen for percentage ratios would make a good problem. Riparian tree pollen, i.e., *Salix*, *Fraxinus*, *Juglans*, and *Ulmus*, makes up the major components of the modern pollen rain. *Juglans* and *Fraxinus* are limited only to the flood plain, according to the pollen rain.

The non-arboreal pollen types have some characteristic profile features. The cheno-ams range across the transect area except for the Palmetto swamp collecting site (MP3). Cyperaceae dominate the swamp (MP3) and march (MP4) sites on the flood plain. The grass profile indicates that the high peaks in the pollen rain are in the upland areas with percentages above 30%. The grass curve declines across the swamps to a recoverable increase near the Hershop Bog (MP1). Compositae pollen in the pollen rain, almost parallels the grass curve except that the percentages at the peaks in the profile are much higher, especially at the Hershop site (ca. 49%).

DISCUSSION

Based upon excellent radiocarbon dating and the unsilted condition of the peat, it appears to be a safe assumption that in the Hershop Bog during the past 12,000 years a pollen record has accumulated without disruption or the intrusion of stream deposited palynomorphs. Thus, the fossil record is representative of the bog, local upland, and regional pollen rains. This pollen record begins prior to the termination of the Wisconsin glacial period and covers the recent. However, there has been an inexactly known amount of erosion of the most recently deposited peat during the past decade or so.

Strong evidence for post-glacial climatic changes in Central Texas is present for the pollen record is not uniform, and a rapid decline in arboreal pollen, especially birch, approximately 10,000 years B.P. appears to mark the end of a pluvial period in Central Texas. The impressive increase in grass pollen, which followed the drop in arboreal elements, suggest a deterioration of upland and stream-side forest caused by a reduction in regional moisture availability. The occurrence of an arid period between 10,000 and 7,000 years B.P. is also indicated by the reduction in Cyperaceae pollen and the many riparian types i.e., Juglans, Celtis, and Carya.

At about 7,000 years B.P., the pollen record of Hershop Bog suggest the start of a gradual change to more mesic conditions as indicated by an increase in Polygonaceae and Umbelliferae pollen and a sudden rise in Cyperaceae and Typha pollen. Oak pollen percentages increase gradually.

The apparent mesic conditions were interrupted at approximately 3,000 years B.P. by a brief slight-arid period which lasted some 2,000 years and was characterized by a sudden increase in grass pollen, a sharp decline in Cyperaceae and Umbelliferae pollen, coupled with stabilizing of the rise in oak pollen. By approximately 1,000 years B.P. the postulated slight-arid period terminated and a return to mesic conditions occurred. This last change as seen in the pollen profile was sufficient to bring a return of riparian types i.e., Juglans, Ulmus, Celtis, and Carya; along with aquatic elements i.e., Cyperaceae and Typha. The pollen record also suggest an invasion of Prosopis and Juniperus occurring during the last 1,000 years.

In order to critically judge the significance of the various components of the pollen profile, a modern pollen rain transect was made. This has proven to be extremely valuable. By comparing vegetational components in the fossil record to the modern pollen rain, certain general assumptions about the paleovegetation of the area can now be tentatively made.

However, it must be recognized that changes in the physical nature of a bog may very well result in changes in the vegetation of the bog itself, thus influencing the pollen profile without significant regional environmental changes. With reference to the latter statement, a question arises as to the general climate during the period of time from about 7,000 years B.P. to about 3,000 years B.P.? The period before and immediately following this 4,000 year span of time had prominent grass peaks. Was the general region during this period being subject to more mesic conditions with increased rainfall, or could changes in the physical nature of the bog, such as daming of its drainage outlet cause ponding on the bog's surface? Surface ponding could have resulted in certain bog plants supplying increased percentages in the pollen rain without any necessary change in the regional climate, and increased percentages of bog pollen types would automatically reduce the representation of regional pollen.

The modern pollen rain transect is quite helpful in the interpretation of pine pollen percentages in the profile. As shown in the Hershop Pollen Profile pine averages close to 4% in the lower meter of the bog deposit. Although sparce in the middle levels, pine persist throughout the sequence but never averages more than 2 or 3% above the 4.0-n level. The modern-pollen rain along the transect demonstrates that current long-distance transport results in 2-3% of pine pollen in the surface-soil samples near the bog. These data suggest that for the past 12,000 years stands of pines have been no closer to the Hershop area than they are at the present time, and that the "isolated" pine stands in Central Texas may have been stable for this period as well.

The vegetational communities around marshes, seeps, and bogs and surface samples in the vicinity of the Hershop site provide insights as to what the local paleo-micro-environment might have been. The dominant understory shrubs growing on and around the South Soefje Bog, one mile north of the Hershop Bog, are <u>Ilex</u> and <u>Myrica</u>. Very active seeps provide abundant water for the "alive" and "quaking" portions of that bog today. <u>Ilex</u> was observed in the modern-pollen rain in the surface collecting area surrounding seeps and springs. The fossil-pollen record indicates that <u>Ilex</u> grew in or around the Hershop Bog between approximately 10 and 12,000 years B.P. The disappearance of <u>Ilex</u> pollen from the profile may have resulted from meander migration of the San Marcos River rather than the regional changes which had more influence on upland plants.

Additional support for a mesic environment during the deposition of the lower meter of the Hershop deposit has been obtained. Analyzed samples from a 0.5-m core taken from the bottom (5.2 - 5.7 n) of a recently discovered peat deposit designated by this writer as East Hershop Bog has revealed a pollen sequence which parallels the Hershop profile. All of the arboreal components observed in the Hershop samples, except _Liquidambar_, were encountered in the East Hershop samples. The birch pollen peak occurred at the 5.7-m level and gradually decreased upwards. Most of the other pollen types were observed at all levels but the birch pollen was absent above the 5.0-m point. Radiocarbon dating of the East Hershop Bog was not obtained and stratigraphic correlations will not be attempted.

Betula pollen from both bogs was carefully and successfully compared to _Betula nigra_ pollen processed from herbarium specimens. Collection data on the herbarium sheets identified birch in East Texas as close as 250 miles to the Hershop site. The average annual precipitation in the East Texas counties where _Betula nigra_ was collected ranges from 40 to 50 inches per year, compared to the 30-35 inches per year in Gonzales County. Since the climatic differences between the current habitat of _Betula nigra_ and the bog area does not include any real temperature variation the author has considered it prudent to refrain from interpreting the time from 12,000 B.P. to 10,000 B.P. as cool-moist. In fact, none of the pollen types encountered in in the bog require any real reduction in temperature to explain their occurrence.

As discussed, the Hershop profile is not uniform and definitely reflects changes in the vegetation since late-pluvial times. Near-by Soefje Bog has been reported (Graham and Heinsch, 1960) to reflect a fairly stable vegetational sequence during the past 8,000 years. Their interpretation has been based upon an unchanging non-arboreal vs. arboreal ratio. Before attempting any correlation of the Hershop and Soefje Bogs, the natures of the two bogs and local plant communities should be taken into account. Thus, differences in the two profiles may be attributed to depositional events and to differences in local plant communities controlled by topography and water availability. The "flood-plain-bounded" Soefje Bog may have stream deposited pollen types laid down during floods. Also, the present Soefje Bog has a thick understory of _Ilex vemetoria_ and _Myrica cerifera_ with species of _Quercus_, _Fraxinus_, _Ulmus_, and _Salix_ composing the surrounding tree types. The local plant community around Soefje Bog may always have been different than that of the Hershop bog. Around the Hershop site and distant hillsides are _Prosopis_ and _Quercus_; both species have lower water requirements. _Carya_ and _Salix_ do follow the watershed leading from the Hershop Bog.

Graham's 4.7-m core from the bottom of the Soefje site was either too shallow or the sediments too young to encounter the arboreal peak seen in the bottom of the Hershop deposit. The greater age of the Hershop deposit can account for perhaps 4,000 years which is sufficient time for some major climatic changes in the Central Texas area not reflected in the Soefje deposit. The Soefje profile indicated that grass pollen fluctuated only slightly, whereas, the grass curve in the Hershop profile shows major changes in pollen percentages. Due to its flood-plain location, perhaps the Soefje site had abundant supplies of water even when the general area was subjected to less mesic conditions which are reflected in the Hershop profile in the sequence designated as the Maximum Grass Pollen Zone.

Some 70 miles to the north, in Lee County, the Patschke Bog (Potzger and Tharp, 1943, and 1947) was cored deeper than the Hershop Bog by 1.5 m. The former probably, but not necessarily, contains a pollen sequence older than the latter. The Patschke Bog has since been destroyed which adds to the following problems in correlation: (a) the Patschke Bog was sampled at one-foot intervals compared to 10-cm intervals in the Hershop; (b) the samples were sent to Indiana for processing and analysis which brings up the question of _Abies_ and other pollen types being contaminants; and (c) from the 22-ft level a total of 10 slides yielded only 50 grains, which seems to be a highly unreliable count. However, a four-fold climatic sequence was proposed by Potzger and Tharp. This sequence is as follows; cool (boreal conifers), to warm-dry (_Quercus_ and grasses), to warm-moist (_Alnus_ and _Castanea_, and then to warm-dry (_Quercus_, _Carya_, and grasses), becoming still drier towards the topmost level of the bog. This climatic sequence is in doubt, and East Texas bogs are being sought in order to study vegetational changes in this area of Texas.

The Gause Bog (Potzger and Tharp, 1954) about 35 miles northeast of the Patschke Bog, in eastern Milam County, was cored to 14 ft and also sampled at 1-ft intervals. It was reported that this bog had _Abies_ and _Picea_ in the lower 1-ft sample indicating a boreal forest. Four years later Graham obtained unused portions of the lower 5 ft of the Gause Bog samples and processed them to verify the reported presence of _Abies_ and _Picea_. He reports the presence of _Picea_ but could not identify any _Abies_ in the material. The re-examined Gause samples also contained no _Castanea_ as previously reported and Graham found differences in the amounts of oak, grass and _Alnus_.

The Franklin Bog (Potzger and Tharp, 1954) in Robertson County, about 25 miles northeast of the Gause Bog, was cored to a depth of 10 ft. _Abies_ was not reported but _Picea_ was. The origin of _Picea_ encountered in the fossil record is currently unknown, but could have been bog spruce from either eastern or western forests. Furthermore, the author is reticent to completely accept the reports of _Picea_ pollen as recent studies have not confirmed its presence in peat supposedly containing this pollen type.

A mesic and perhaps cooler environment is suggested for the lower strata in several rockshelter sites from the Amistad Reservoir Area of West Texas (Bryant, 1966a; McAndrews and Larson, 1966). The assumed age for these strata is greater than 10,000 years B.P. High peaks in pine and the possible presence of spruce were observed in these strata. From about 10,000 to 5,000 years B.P. the climate in the Amistad region became drier yet the vegetation as reflected by the pollen record could be characterized as remaining mesophytic. This period was followed by a general change to aridity with minor fluctuations. It is apparent that both West and Central Texas pollen profiles indicate a post-glacial dry period of considerable length.

The pollen profiles from playa lakes on the Llano Estacado have been summarized by Oldfield and Schoenwetter (1964). The Lubbock Subpluvial between 11,000 and 10,000 years B.P. has been reconstructed as a pine woodland which stretched across the Texas High Plains. The period corresponds to Flint's (1963) Valders Readvance in Central North America. This period was followed by the San Jon Subpluvial and Yellow House Interval which is matched in the Amistad area and to some degree the Hershop area.

The late-Quaternary climate in southern Arizona as outlined by Martin (1963) begins with cool-humid conditions during the late-pluvial period to about 11,000 years B.P. And, from about 11,000 to 8,000 years B.P. a period roughly corresponding to Antev's (1955) Anathermal period, the climate was warm-arid. This proposed period corresponds closely to the assumed arid Maximum Grass Pollen Zone in the Hershop sequence. Martin argues that Antev's Altithermal (from 7,500 to 4,000 years B.P.) was not dry but was characterized by intensive summer rainfall. According to Martin, the pollen and biogeographic records fail to support any biologically important drought occurring in the Southwest between 7,500 and 4,000 years B.P. While it is as yet impossible to correlate pollen profiles from Central Texas to those from Arizona, it can be stated that the climate in Central Texas during the Altithermal was not excessively mesic and may have been only less arid than the preceding period (Maximum Grass Pollen Zone). Deevey and Flint (1957) coined the term Hypsithermal to include the warmer part of the post-glacial period between 9,500 to 2,500 years B.P. As discussed earlier, in Central Texas the role that temperature played in the development of plant communities may have been minimal in comparison to available moisture.

SUMMARY

Fossil pollen from cores (5.4 and 5.0 m) from the Hershop Bog, located in Gonzales County, Texas, was studied to obtain information about the late-Quaternary vegetational history and climate of Central Texas. Samples were processed by a technique suggested by Faegri and Iverson (1964) and counts using fixed sums of 200 grains were made at 10-cm intervals. A tri-county (50 mile) modern pollen transect was employed to obtain a modern pollen rain which was compared to the fossil pollen record. Extensive radiocarbon data was collected from a series of probes allowing a detailed chronology of vegetational trends to be given. Four pollen zones have been established to delineate the vegetational changes. From bottom to top the four zones are: Birch Pollen Zone; Maximum Grass Pollen Zone; Umbelliferae Pollen Zone; and the Oak-Mixed Grass Pollen Zone. The vegetational sequence indicates that a mesic period existed from the beginning of the bog deposition to about 10,000 years B.P. A trend toward arid conditions followed as indicated by an increase in grass pollen and decrease in tree pollen. This period existed until about 7,000 years B.P. possibly changing again to slightly more mesic as reflected by the drop in grass and increase in Umbelliferae pollen and aquatic herbs. This period was

interrupted about 3,000 years B.P. by a slight-arid period which was terminated by a return to mesic some 1,000 years B.P. The pollen profile of this period is characterized by a high oak peak and the presence of riparian tree types.

Problems in evaluating previous pollen analytic studies are such that no real attempt to make correlations among Hershop, Soefje, Patschke, Gause, and Franklin bogs has been made. There is a need for renewed palynological efforts in East Texas.

Considering the distance, diversity in present climate, biomes, and topography it is difficult to make meaningful correlations with pollen sites across the Edwards Plateau in West Texas at the present time.

APPENDIX

Extraction Techniques for Peat Samples

Among the outstanding advantages in having peat as the vehicle for fossil pollen are: (1) due to its very origin, peat has enormous amounts of preserved pollen; (2) the fact that most peat deposits are formed in a depositional basin and materials washed in or blown in usuaully remain to be preserved; (3) due to the chemical changes of the organic debris in aquatic environments, peat bogs are highly acidic and act like a preservative for pollen; (4) because of the abundant supply of pollen per unit of peat, only a very small quantity is needed for processing.

Seven basic steps were followed in extracting pollen form the Hershop Bog samples.

<u>Step 1</u> <u>Physical separation of coarse clastics and the plant debris</u>.

Place a small amount (2-3 cc) of the peat sample in 250 ml beaker. Add 15-20 ml of either H_2O or 10% HCl to break up the material. Use stiring rod or swirl the suspension in order to separate the heavy clastic sediments from the organic material. Let the sample sit 10-15 seconds, then decant liquid and suspended material. Discard clastic sediments and repeat if necessary. Screen sample using 200 mesh screen to separate plant fragments, jet water onto screen to remove pollen from plant debris. Centrifuge and discard liquid fraction. Transfer sediment to 100 ml plastic centrifuge tube.

Step 2 Hydrofluoric Acid Treatment

Add 10-15 ml of concentrated HF to sediment in plastic centrifuge tube and stir with plastic stirring rod (wear rubber gloves and work under fume hood). Place on hot water bath for 10-15 minutes and stir frequently. Remove from water bath and centrifuge. Discard liquid fraction.

Step 3 Hydrochloric Acid Treatment

Add 15-20 ml of concentrated HCl and stir. Then add enough 10% HCl to fill tube 3/4 full and stir well. Centifuge and discard liquid fraction. Check for colloids and repeat if necessary. Wash sample several (3-5) times with water.

Step 4 Potassium Hydroxide Treatment

Add 20-30 ml of 10% KOH to sample and place on water bath for 10 minutes. Remove sample, centrifuge, and decant liquid fraction. Wash sample with distilled water 2-3 times, followed by centrifuging and decanting each time. Flush sample onto a 149 micron mesh screen covering a 250 ml beaker. Screen sample using a jet of water and discard plant debris from screen. Pour sample back into a 100 ml tube, centrifuge, and decant liquid fraction. Acidify sample by washing once with 10% HCl and transfer sample to a 12 ml centrifuge tube. Centrifuge and decant liquid fraction.

Step 5 Zinc Chloride Density Separation

Add 10-11 ml of Zinc Chloride solution (having specific gravity ca. 1.65) to sample and stir well with rod. Centrifuge at 2500 rpm for 3 minutes. Decant liquid fraction into 100 ml beaker. Check residue for pollen before discarding. Dilute liquid fraction sample with double amount of 10% HCl, centrifuge well and discard liquid fraction. Wash sample with Glacial Acetic Acid, centrifuge and decant liquid fraction.

Step 6 Acetolysis Treatment

Add 10 ml of Acetolysis mixture (9 parts acetic anhydride and 1 part concentrated sulfuric acid added slowly together) to the sample in a 12 ml centrifuge tube. Stir well and place on water bath for 10-15 minutes. Centrifuge the sample and decant liquid fraction. Fill tube with Glacial Acetic acid, stir, centrifuge, and decant liquid fraction. Wash sample 3-4 times with distilled water.

Step 7 Dehydration, Staining, and Preservation

Add 10 ml of 95% alcohol, stir, centrifuge, and decant liquid. Repeat 2-3 more times. Then use 100% alcohol for complete dehydration of sample, centrifuge, and decant liquid.

Add 3-3 ml of Benzene to sample and transfer sample to a 5 ml shell vial. Centrifuge, and decant Benzene. To the concentrate, add enough silicone oil (2,000 cs) to suspend material to desired amount. Allow sample to stand on warming plate to evaporate Benzene. Cork the vial to prevent contamination.

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